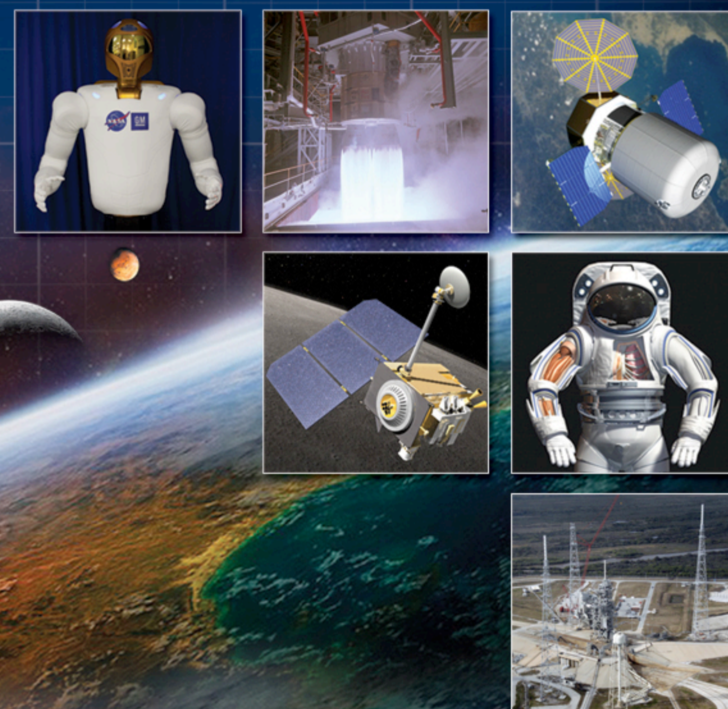
National Aeronautics and Space Administration

Flagship Technology Demonstrator (FTD)
Environment Control & Life Support (ECLS)



Enterprise Workshop

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May 26, 2010

Disclaimer

- This chart set was presented on May 26, 2010 at the NASA Exploration Enterprise Workshop held in Galveston, TX. The purpose of this workshop was to present NASA's initial plans for the potential programs announced in the FY2011 Budget Request to industry, academia, and other NASA colleagues. Engaging outside organizations allows NASA to make informed decisions as program objectives and expectations are established.

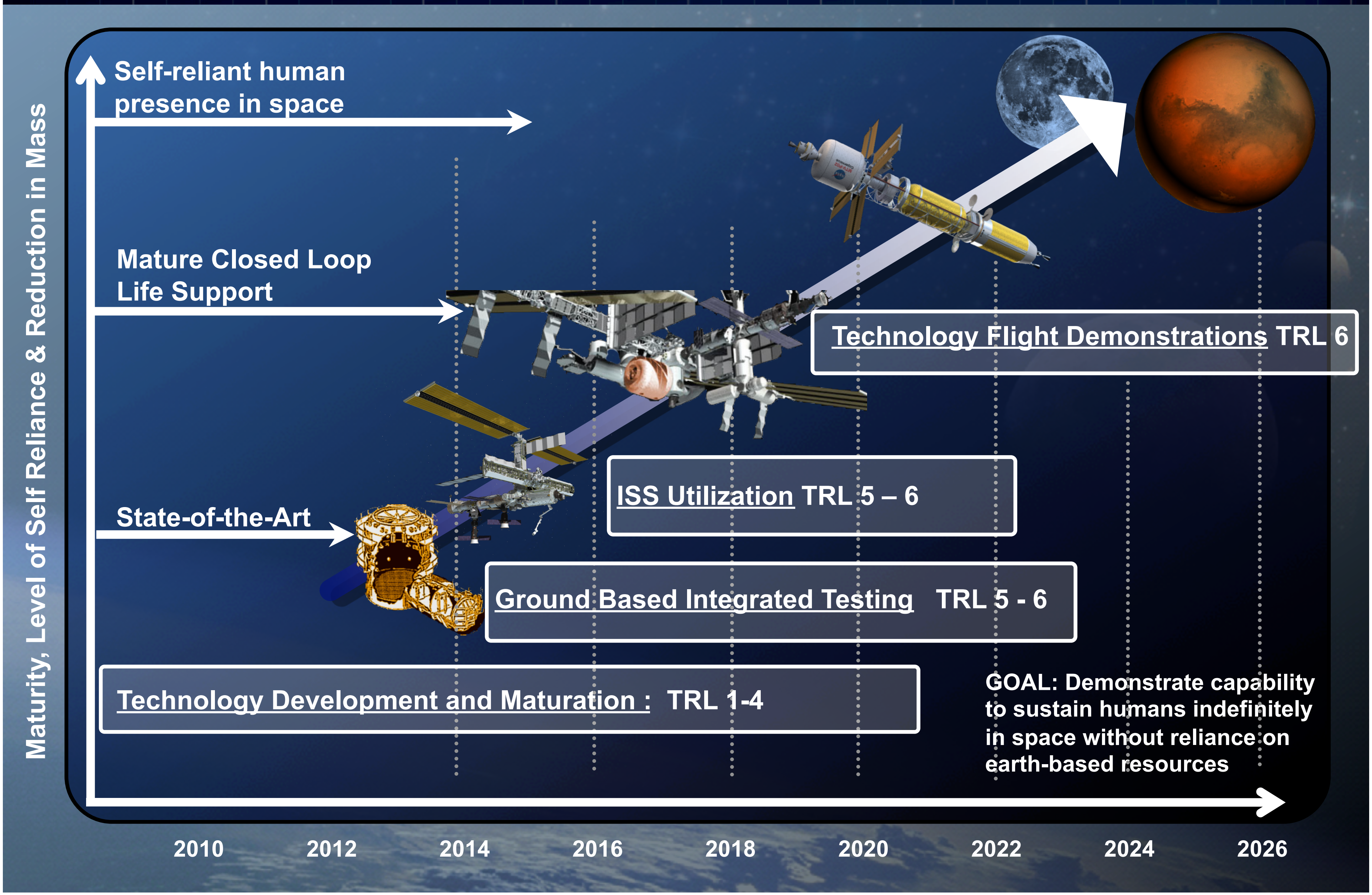
- The following charts represent at "point of departure" which will continue to be refined throughout the summer and the coming years. They capture the results of planning activities as of the May 25, 2010 date, but are in no way meant to represent final plans. In fact, not all proposed missions and investments fit the in budget at this time. They provide a starting point for engagement with outside organizations (international, industry, academia, and other Government Agencies). Any specific launch dates and missions are likely to change to reflect the addition of Orion Emergency Rescue Vehicle, updated priorities, and new information from NASA's space partners.

Purpose / Scope

- **Purpose:** The purpose of this presentation is to inform the audience of NASA's ECLS technology development objectives, and what role the FTD ECLS Request For Information(RFI) will have in achieving the agency goals.

- **Environmental Controls and Life Support (ECLS):**
  - ECLS is composed of all the necessary components, resources and technologies needed to provide a live-able, controllable and recoverable environment for human space flight.
  - For the purposes of this presentation "ECLS" includes only those functions listed below:
    - Atmospheric Revitalization
    - Water Recovery
    - Waste Management
    - Environmental Monitoring
    - Pressure Control
    - Thermal Control
    - Bio-regenerative

ECLS for Human Exploration



Basic Human Life Support Requirements
Consumables & Waste

Consumables	Kilograms per person per day	
Gases		**0.8**
Oxygen	0.84	
Water		**23.4**
Drinking	1.62	
Water content of food	1.15	
Food preparation water	0.79	
Hygiene Water	6.82	
Clothes wash	12.50	
Urine flush	0.50	
Solids		**0.6**
Food	0.62	
Soaps & personal products	0.05	
TOTAL		**5 to 25**

Wastes	Kilograms per person per day	
Gases		**1.0**
Carbon Dioxide	1.00	
Water		**23.7**
Urine	1.50	
Perspiration/respiration	2.28	
Fecal water	0.09	
Hygiene Water	6.51	
Clothes wash	11.90	
Urine flush	0.50	
Humidity condensate	0.95	
Solids		**0.2**
Urine	0.06	
Feces	0.03	
Perspiration	0.02	
Shower & hand wash	0.01	
Clothes wash	0.08	
TOTAL		**5 to 25**

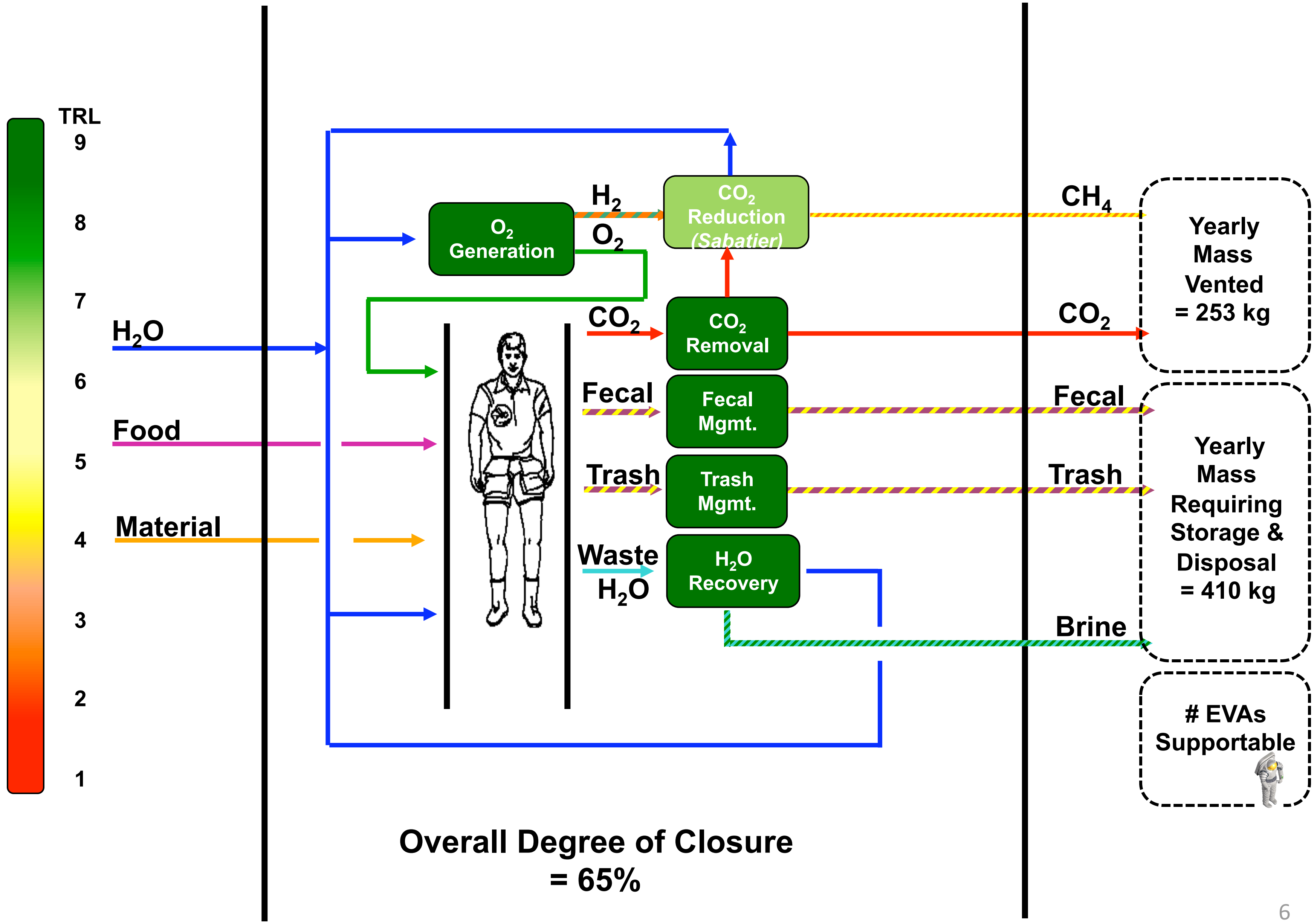
†Notional – values not based on any specific mission

Black: Quantities fixed – Determined by human metabolic requirements

Red: Quantities variable - Mission requirements for LSS not defined

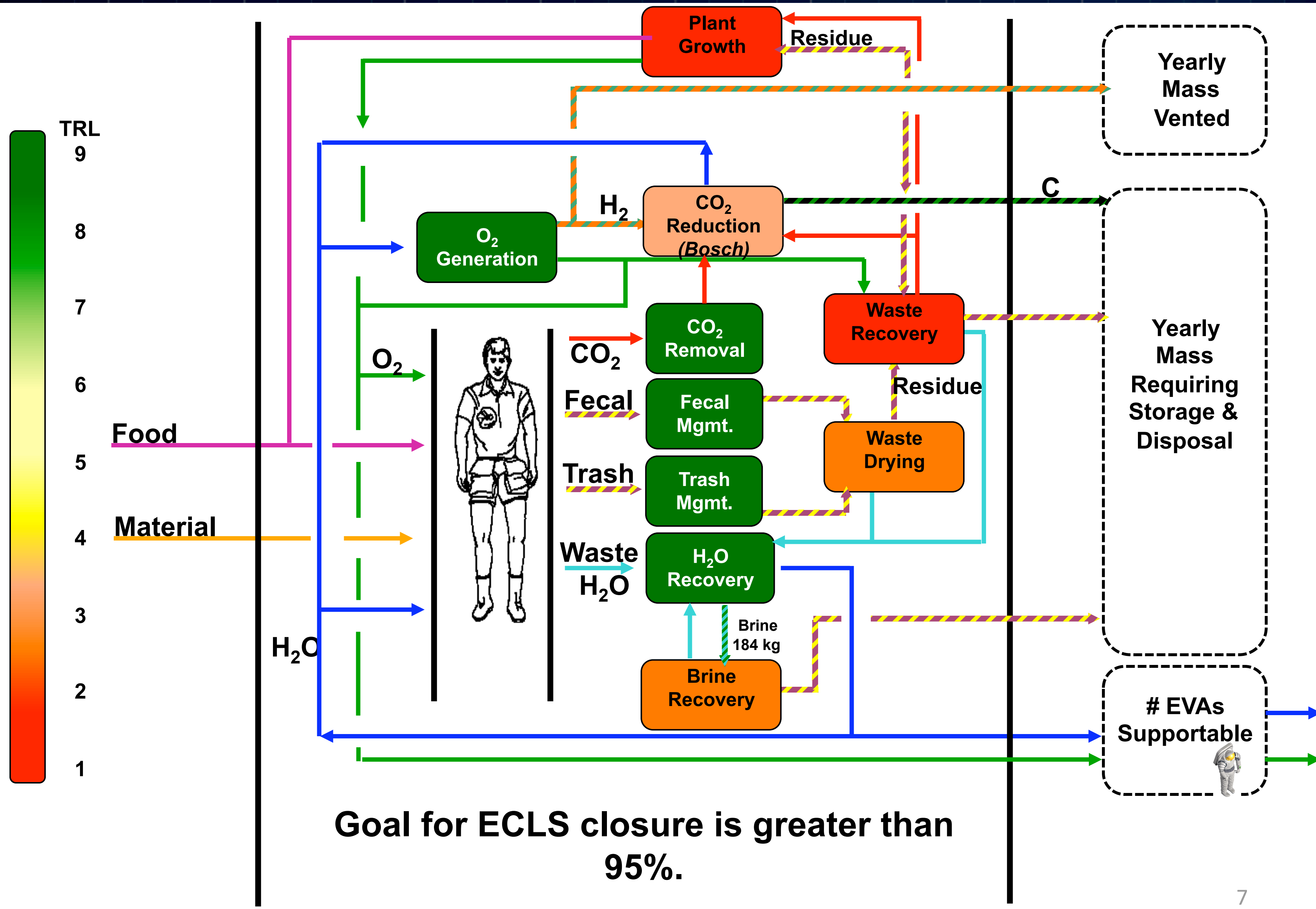
Certain wastes and thermal fluids may be lost during EVA if not recovered

ECLSS Loop Closure: ISS 2010 + CH_4 Post-Process (kg per person per year)



Overall Degree of Closure = 65%

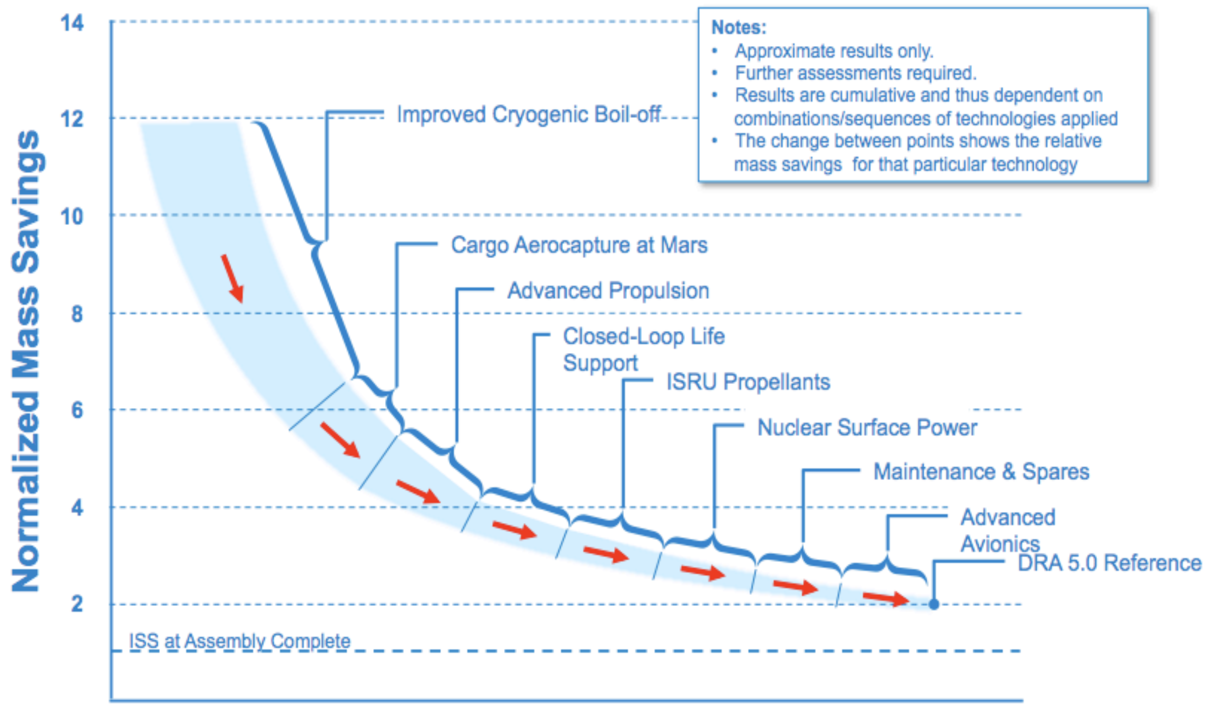
ECLSS Loop Closure: ISS + Bosch (or equivalent) + Brine Recovery + Waste Drying + Waste Recovery + Food Production (kg per person per year)



Goal for ECLS closure is greater than 95%.

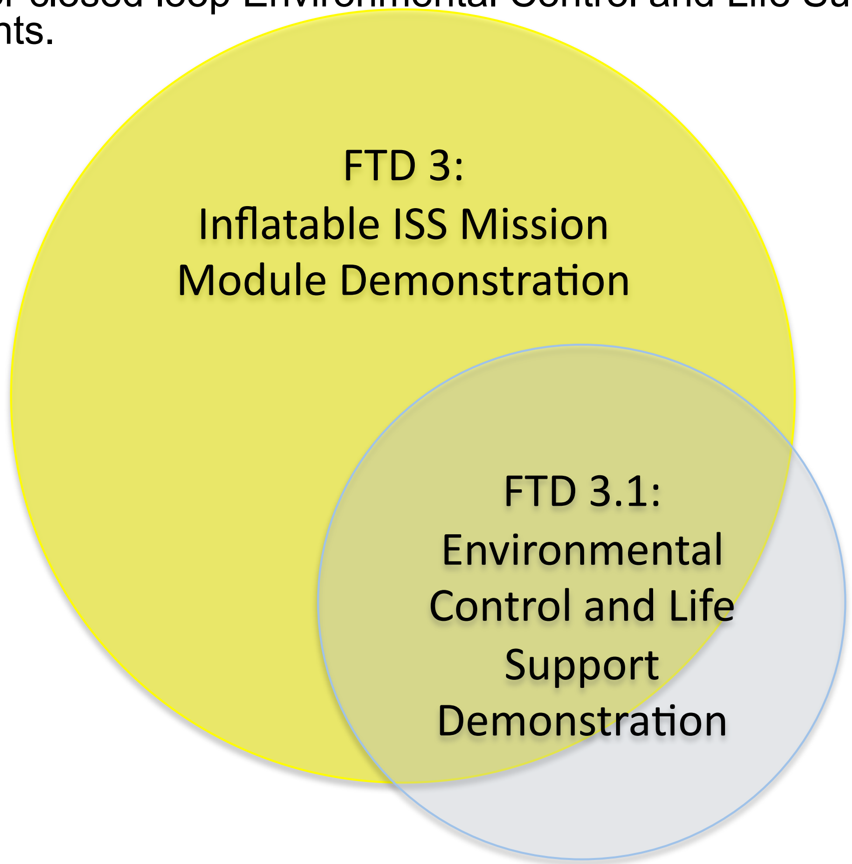
ECLS Goals

- **Goal: Increase the amount of overall ECLS system closure, to extend human presence in the solar system by:**
  - Decreasing:
    - Mass
    - Power consumption
    - Resupply requirements
    - Overall system volume
    - Lost resources to the space environment
  - Increasing:
    - System performance
    - Reliability
    - Recovered resources



FTD Overview

- The FTD ECLS technology is part of FTD 3 - Inflatable ISS Mission Module Demonstration.
  – FTD 3 Mission Goal:
    - Demonstrate integration of advanced technology systems for ECLSS, waste management and reduced logistics with an inflatable structure… advanced lightweight materials.
- The point of departure mission currently shows that the delivery of the Inflatable Module to International Space Station (ISS) is to occur in 2015. The Inflatable Module is to be used for a test bed for closed loop Environmental Control and Life Support (ECLS) technology advancements.



FTD ECLS Overview

- **Mission Description:** To advance, demonstrate, and integrate technologies needed for advancing the current technology level of space rated ECLS hardware and closing the gap to a near closed-loop ECLS system.
- **Mission Goal:** To reduce the mass, power and resupply requirements when measured against the current state of the art space flight qualified hardware. Coupled with increasing the performance output and reliability.
  - Demonstrate a closed loop life support system with human in ground test facilities.
  - Demonstrate a closed loop life support system with humans in space.
- **Functionality:** Areas of focus for Flagship ECLS
  - Atmospheric Revitalization
  - Water Recovery
  - Waste Management
  - Habitation System
  - Environmental Monitoring
  - Pressure Control
  - Fire Protection
  - Thermal Control
  - Bio-regenerative

Courtesy: Schunk & Roman, 2005.

FTD ECLS Overview (continued)

- **Key Mission Milestones:**
  - Startup 2011; for selection of mission set and ground development
  - Start of FTD technology development phase in 2012; continued ground development
  - Phased Deliveries to ISS 2015 to 2016
  - Phased demonstration from 2015 to 2018
- **Assumptions / Ground rules:**
  - The ECLS hardware will launch as stand alone components that can be tested within the inflatable module or within the existing ISS.
  - The current design of the inflatable module will contain an airlock to allow for reduced pressure operations.
  - The inflatable module will be designed with the required mounting interfaces and supporting resources to support the ECLS equipment. These interfaces are still TBD at this point.
  - The ECLS technology mission will not start until FY'12. Technology maturity will be advanced during FY'11, in support of the Flagship mission.
  - The content of the FTD ECLS mission set has not been baselined; only notional technologies have been selected for budget development activities

FTD ECLS Mission Objectives

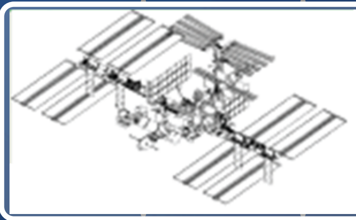
- ECLSS Flagship mission objectives are depicted in the table below. The Allocated Measure of Effectiveness shown is the minimum to achieve for the first mission.

Technology Goals	Technology Objectives	Measure of Effectiveness for Inflatable Mission
<u>Technology Goal 4:</u> Advance, demonstrate and integrate technologies needed for closed loop life support	**Objective 4-1:** Demonstrate a closed loop life support system with humans in ground test facilities.	A complete closed loop life support system is demonstrated in ground test facilities that can sustain 3 crewmembers for 2 years
	Objective 4-2: Demonstrate a closed loop life support system with humans in space.	A complete closed loop life support system is demonstrated in space that can sustain 3 crewmembers for 2 years

FTD ECLS Timeline Overview

Flagship Flight Demonstration

•Flight validation of closed loop life support



ISS Utilization

•Gather lessons learned from operational systems on ISS
• Targeted DTO's that evaluate gravity sensitivity

Ground Based Integrated Testing & Demonstration

• Advance TRL Maturity of subsystems and systems

Technology Development and Maturation

•Advance TRL Maturity of subsystems and process technologies to TRL 4 & 5

Technology Maturation and Closure

2010 2012 2014 2016 2018 2020

FTD ECLS RFI Summary

- **ECLS RFI Overview:**
  - The key function of the FTD ECLS study team was to develop section 8 of the FTD RFI.
  - On 5/18/10 the NASA Head Quarters released the FTD RFI covering all 6 technology areas.
  - The goal of the FTD ECLS RFI is to collect data on what current State Of the Art (SOA) technologies and capabilities are available to support the develop of the FTD ECLS mission set.
- **ECLS RFI Layout**
  - Each ECLS sub-section is broken out as follows:
    - Goal
    - Current State of the Art for flight-approved hardware and performance of that equipment
    - Response opportunities

FTD ECLS RFI Summary

- **Section 8 of the RFI is broken down into the following sub-sections:**
  - 1.0 Atmospheric Revitalization
  - 2.0 Water Recovery
  - 3.0 Waste Management
  - 4.0 Environmental Monitoring
  - 5.0 Pressure Control
  - 6.0 Thermal Control
  - 7.0 Bio-Regenerative Life Support & Food Production
  - 8.0 Integrated system-level ECLS approach

Closing

- **Question or Comments?**

- **Contact:**

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Back-Up

FTD ECLS RFI Sub-Section #1

1.0 Atmospheric Revitalization:

- **Goal:** Demonstrating integrated core functional process technologies and/ or process design solutions to improve upon the ISS atmosphere revitalization (AR) subsystem equipment and architecture is a central interest.
- Table 1 provides comparative performance targets relative to the ISS as the state-of-the-art (SOA).

FUNCTIONAL AREA	TRADE SPACE	PERFORMANCE PARAMETER & UNITS	SOA VALUE	TARGET VALUE	SOA BASIS
PARTICULATE REMOVAL & DISPOSAL	COMBINED - Primary screening, secondary separation, & tertiary separation	Specific Mass (kg-h/g PM)	925	300	ISS BFE
		Specific Power (W-h/g PM)	1,615	560	
CORE AR SUBSYSTEM	TRACE CONTAMINANT REMOVAL	NH_3 sorbent capacity (mg/g sorbent)	11	>50	ISS TCCS
		Dichloromethane adsorption capacity (mg/g)	0.05	>0.12	
		Non-methane VOC oxidation temperature (°C)	>250	<200	
		System Specific Mass (kg-h/kg air)	4	<3	
		System Specific Power (W-h/kg air)	8	<2	
	CO_2 REMOVAL	Specific Mass, (kg-h/kg CO_2)	826	670	ISS CDRA
		Specific Energy (W-h/kg CO_2)	2,174	560	
LOOP CLOSURE	OXYGEN CONDITIONING (COMPRESSION)	Specific Mass (kg-h/kg O_2)	83	<30	ISS ORCA
		Specific Power (W-h/kg O_2)	135	<100	
	OXYGEN GENERATION	Specific Mass (kg-h/kg O_2)	1,560	1,000	ISS OGA
		Specific Power (kW-h/kg O_2)	10	<7.5	
	CO_2 REDUCTION	Specific Mass (kg-h/kg H_2O produced)	1,960	<1,600	ISS SABATIER CRA
		Specific Power (W-h/kg H_2O produced)	2,000	<1,600	

Table 1

FTD ECLS RFI Sub-Section #1 (continued)

1.2 AR Loop Closure Functional Elements

Functional elements promoting loop closure include CO_2 reduction, CO_2 handling, CO_2 reduction product handling, and gaseous O_2 production.

1.2.1 CO_2 Reduction

The NASA and the U.S. aerospace community have a greater understanding of Sabatier-based CO_2 reduction processes and equipment than any other approach to achieving AR subsystem loop closure.

1.2.1.1 Response Opportunity

Interest in improved Sabatier-based processes using novel reactor designs, novel catalyst supports/substrates, and reaction product separations techniques (e.g. H_2/hydrocarbons, CO/reactants) are of interest for demonstration. Rapid development and demonstration of Bosch reactor design concepts for both recycle and series reactors is of great interest. NASA is also seeking information on alternatives method to reduce the level of CO_2 within the space craft environment, outside of the example listed above.

1.2.2 CO_2 Reduction Post-processing

The extent of CO_2 reduction to various products dictates the need for product handling and/or post-processing.

1.2.2.1 Response Opportunity

Techniques for handling and disposing of solid carbon and hydrocarbon products from CO_2 reduction processes are of interest to the NASA for demonstration. Collection, handling, and disposal of solid carbon products from Bosch-based processes and from the pyrolysis of Sabatier process-produced CH_4 are candidates for demonstration. Techniques for converting CO_2 reduction products to useful products such as organic synthesis precursors and/or fuels (e.g. methanol, acetylene, or other) are of interest to NASA for demonstration. NASA is also seeking information on alternatives method to handle post processing products within the space craft environment, outside of the example listed above.

FTD ECLS RFI Sub-Section #2

2.0 Water Recovery (WR)

– Goal: Demonstrate technologies in ground based test facilities and with humans in space to improve upon existing State Of the Art (SOA) space-certified systems typified by the water recovery system.

2.1 Primary Water Processing

The current WR system onboard ISS utilizes separate systems for urine and humidity condensate processing. For urine processing, a rotary vacuum distillation system is utilized to recover approximately 70% of water from urine.

2.1.1 Response Opportunity

Although NASA's current water recovery system architecture separates urine from other wastewater sources for primary processing, a variety of system configurations are possible for an integrated water recovery system. Primary processors should be capable of recovering greater than 85% of total input wastewater, and greater than 70% of urine if treated separately. The water quality of the product water should include a total organic carbon concentration of less than 50 mg-C/L and remove inorganic contaminants to concentrations approaching the NASA potable water requirements specified in the NASA Manned System Integration Standards (NASA-STD-3000). Among the technologies of interest are membrane-based systems and biological-based systems. The system should also demonstrate compatibility with both current and alternate wastewater stabilization chemicals.

2.2 Brine Management

Many technologies that can be used in water recovery systems, such as distillation or membrane processes, produce concentrated waste called brine. Development of technologies for recovery of water from brine will enable closure of the water loop and approach 100% recovery of wastewater. There is currently no brine water recovery system onboard ISS.

2.2.1 Response Opportunity

Current needs in brine water recovery include the development of technologies that will recover over 90% of the water from the brine and minimize energy and consumable use.

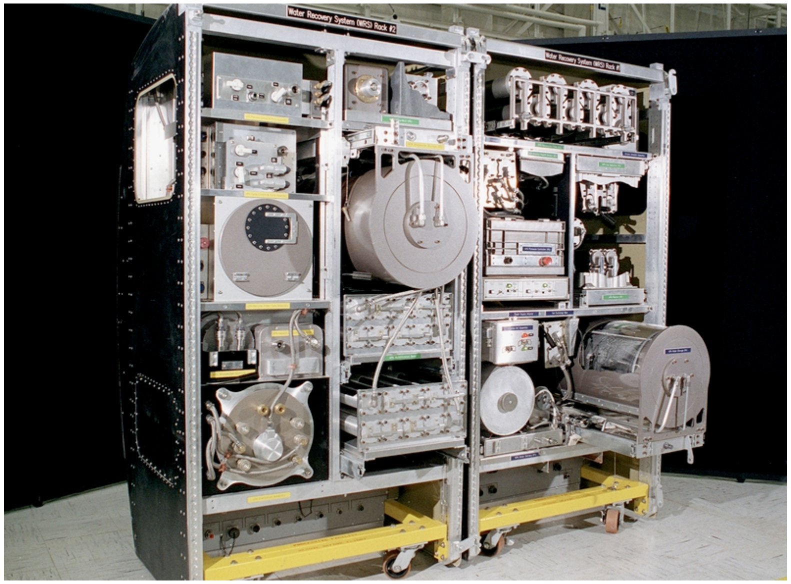
FTD ECLS RFI Sub-Section #2 (continued)

2.3 Post- Processing and Disinfection Systems

The current WR system onboard ISS utilizes catalytic oxidation for post-treatment and disinfection of recovered water. The catalytic oxidation system oxidizes residual organic compounds in the water following treatment by the ion exchange and activated carbon steps of the primary treatment system. The catalyst operates at 127 °C; this elevated temperature provides for disinfection of the processed water; however, this temperature also requires the system to operate at an elevated pressure to keep the water in a liquid phase.

2.3.1 Response Opportunity

Opportunities exist for the development of efficient post-treatment technologies that operate a lower temperature and pressure than the current catalytic oxidation system. Technologies of interest include improved catalysts that operate at less than 100 °C, photolytic, and photo catalytic systems. In addition, technologies that ensure the microbial stability of the recovered water are also of interest.



FTD ECLS RFI Sub-Section #3

3 Waste Management

– Goal: Demonstrate technologies in ground based test facilities and with humans in space to improve upon existing State Of the Art (SOA), micro-gravity, space-certified systems that manage dry and wet waste.

3.1 Volume Reduction

The Key Performance Parameter (KPP) for volume reduction of trash is the percentage of reduction that can be achieved in a micro-gravity space environment. Current SOA for space flight are the manual compactor and Shuttle Extended Duration Orbiter (EDO) feces compaction, which can achieve an estimated 50% reduction in volume.

3.1.1 Response Opportunity

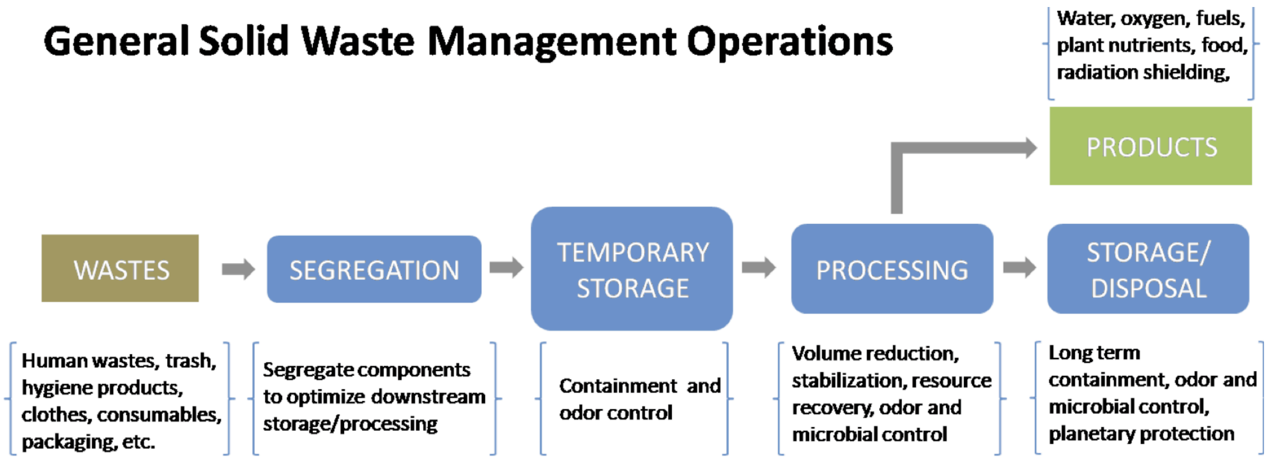
To that end, NASA is seeking input for technology that can achieve > 90% volume reduction in a micro-gravity space environment. Some examples of such technologies are heated and unheated compaction.

3.2 Water Recovery

The KPP for water recovery is the percentage of water recovered from waste that can be achieved in a micro-gravity space environment. Currently NASA does not recover water from its trash aboard the Shuttle or ISS.

3.2.1 Response Opportunity

To that end, NASA is seeking input for technology that can achieve high levels of water recovery. Water recovery from 50% to 99% (90% or higher is preferred) is desired from wet trash sources in a micro-gravity space environment. Technologies include but are not limited to drying, distillation, and evaporation.



FTD ECLS RFI Sub-Section #4

4 Environmental Monitoring

– Goal: Demonstrate integrated technologies and/or design solution to improve upon existing State Of the Art (SOA) micro-gravity space-certified systems by improving/reducing overall mass, accuracy, power, reliability, and volume. The monitoring system should require little or no calibration, as stability of calibration chemicals is a concern. The system should operate for more than a year while requiring minimal to zero consumables. It must operate at reduced pressure (pressure range: 8.2 psia - 14.7psia) found in the module, and varying pressure should not require recalibration.

4.1 Improve accuracy and reduce size of existing air monitors.

Volatile Organic Analyzer (VOA). 44.5 kg, 22 liters, measures about 30 volatile organic compounds simultaneously. Not currently operating. Major Constituent Analyzer (MCA) 54 kg, 22 liters. Measures major constituents in cabin air, including oxygen, carbon dioxide, nitrogen, and water vapor. Oxygen accuracy is less than 6 torr error. Compound Specific Analyzer/Combustion Product Analyzer (CSA/CP) Event monitor: handheld, battery powered, monitors oxygen and carbon monoxide.

4.1.1 Response Opportunity:

Solutions for trace gas and major constituents monitoring of considerably lower mass and volume. A 50% reduction in mass over current flight technology should be considered minimal. Furthermore, oxygen partial pressure accuracy should have an error of < 1 torr. Event monitors should operate continuously. Technologies and/or processes to assure that air is monitored following a fire event, to determine when the air is safe to breathe. This may involve ruggedizing or protecting sensing technologies. See also section 7.3.

4.2 Improve capability and reduce size of existing water monitors. Reduce crew time required for operation.

Total Organic Carbon Analyzer. (TOCA). Measures TOC in water samples, requires crew operation. Microbial Test Kit. Qualitative assessment of bacterial colony count.

4.2.1 Response Opportunity:

Analysis of biocides, identification of organics, monitoring of inorganic targets. Identification of hazardous pathogens without colony amplification, using minimal consumables.

FTD ECLS RFI Sub-Section #5

5 Pressure Control

– Goal: Demonstrate integrated technologies and/or design solution to improve upon existing State Of the Art (SOA) micro-gravity space-certified systems for pressure control by providing new ways/methods to resupply oxygen and nitrogen, provide higher pressure storage tanks, minimizing gas losses due to extravehicular activities, and scavenging excess oxygen and nitrogen from other systems or vehicles.

5.1 Resupply Oxygen/Nitrogen

The current method for resupplying oxygen and nitrogen to a space vehicle to support vehicle subsystem and operation needs is to bring up high pressure oxygen and nitrogen in supply tanks. This requires a large amount of volume, weight, and support hardware to provide the oxygen and nitrogen.

5.1.1 Response Opportunity

To that end, NASA is seeking input for technology that can achieve near zero boil off cryogenic storage or other novel ways to provide oxygen and nitrogen to an on-orbit vehicle and be able to transfer it to a 3000 to 7000 psia storage tank(s).

5.2 High Pressure Storage Tanks

The current SOA micro-gravity space-certified oxygen and nitrogen tank storage is a composite overwrap pressure vessel that has a volume of 15.1 ft3, and maximum design pressure of 3400 psia, and can operate in a temperature range of -60 to 150 degF. It would be desirable to go to a higher storage pressure.

5.2.1 Response Opportunity

To that end, NASA is seeking input for technology that can achieve greater than 3400 psia storage pressure. It would be preferred to be in the range of 6000 – 7000 psia.

FTD ECLS RFI Sub-Section #6

6 Thermal Control

– Goal: Demonstrate integrated technologies and/or design solution to improve upon existing State Of the Art (SOA) space-certified systems by decreasing the mass and volume and/or increasing the reliability, maturity, efficiency, and/or performance of a thermal control system in a man rated space volume. An effective thermal control system must provide three basic functions to the vehicle design. The three critical functions are heat acquisition, heat transport, and heat rejection.

6.1 Thermal Control – Heat Acquisition

Heat acquisition is the process of transferring thermal energy from the heat source to the thermal control system. The heat source from which the energy is acquired can range from various avionics boxes to metabolic heat loads from the crewmembers. There are several different types of hardware components that perform the function of heat acquisition.

6.1.1 Response Opportunity

- To that end, NASA is seeking input of heat acquisition technologies as follows:
- Low mass/volume and high performance heat exchangers (both air/liquid and liquid/liquid heat exchangers).
- Low mass and high performing cold plates.
- Condensing heat exchangers that address/preclude microbial growth and/or allow passive condensate separation.

6.2 Thermal Control – Heat Transport

The second critical function of a thermal control system is heat transport and involves the movement of thermal energy from one region to another. The overwhelming majority of manned United States spacecraft have relied on a pumped fluid loop, but a more passive approach may be considered for some applications.

FTD ECLS RFI Sub-Section #6 (continued)

6.2.1 Response Opportunity

- Inputs for heat transport technologies may include, but may not be limited to the following:
- Thermal control system working fluids that possess desirable fluids properties (thermal conductivity, specific heat, viscosity, etc…) and have a low freeze temperature.
- Thermal control system working fluids that are non-toxic and are non-corrosive to aluminum systems.
- Thermal control system working fluids that are doped with nanoparticles to enhance the fluid's thermal conductivity.
- Low mass variable conductance devices.
- Low mass, highly conductive, and flexible heat straps.
- Microgravity gas-liquid separators.

6.3 Thermal Control – Heat Rejection

The third and final function of an effective thermal control system is heat rejection. As the name implies, heat rejection is the process of rejecting the excess thermal energy acquired by the thermal control system to the external environment. This function is typically accomplished using radiators, but can also be performed by evaporators, sublimators, phase change materials, etc.

6.3.1 Response Opportunity

- NASA is seeking input of heat rejection technologies as follows:
- Variable heat rejection thermal control systems capable of operating in a wide range of environments and rejecting a large range of heat loads. Some example technologies include variable emissivity devices, variable active surface area radiators, etc…
- Low mass, highly efficient evaporative heat sinks.
- Low mass, high performing supplemental heat rejection devices.
- Low mass/volume and high performance phase change material heat exchangers capable of operating in microgravity.
- Flexible and/or deployable radiators.

FTD ECLS RFI Sub-Section #7

7 Bio-regenerative Life Support and Food Production

7.1 Food Growth

- Goal: Demonstrate the capability to grow supplemental food crops for exploration missions, including micro-gravity transit missions and reduced g surface settings. These could focus on vegetables and small fruits that might add variety, flavor, color, and texture to the crew's diet along with a source of bio-available nutrients and antioxidants. Temperature, humidity and CO_2 control could be provided by the cabin environment, or more complex approaches could include these factors in the chamber controls. Sizing for ISS might range from ~0.25 to 2 m^2 growing area to just demonstrate production of some supplemental foods.

8 Integrated System Level ECLS Approach

– Goal: Demonstrate integrated technologies and/or design solution to improve upon the integration of the SOA of ELCS systems and sub-systems by decreasing the mass and volume and/or increasing the reliability, maturity, efficiency, and/or performance of the complete end-to-end ECLS network of components.

8.1 Response Opportunity:

NASA is seeking out new and innovated ideas for the integration of all the ECLS components into a seamless package to decrease the mass and volume and/or increase the reliability, maturity, efficiency, and/or performance as the complete ECLS system. The key functions for integration are air revitalization, water recovery and waste management.